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ENVIRONMENTAL PERSISTENCE AND MIGRATION OF PENTACHLOROPHENOL, WOOD POLE PRESERVATIVE PART I: LITERATURE REVIEW

Report No. 88-258-K

W.P. Mortimer
Environmental Science Section
Chemical Research Department

ABSTRACT

Pentachlorophenol (PCP) is a pesticide used mainly by the wood preserving industry. Although it is relatively persistent in the environment, it is lost through photo- and bio-degradation under some circumstances. The physico-chemical properties that determine the environmental fate of PCP vary with pH, so the expected extent of potential contamination is site-dependent. Preliminary studies of PCP migration from ground-line re-treated poles found that, in the surface soil, the zone of high concentration was very small (a few centimetres). Toxicity data is reviewed, fugacity fate modelling results are presented and current research needs are discussed.

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EXECUTIVE SUMMARY

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Chemical Research Department

Pentachlorophenol (PCP) is widely used by the electric utility industry as a wood preservative for transmission and distribution poles. It has recently been the subject of review by Agriculture Canada due to its potential for negative health and environmental effects.

PCP is commonly found throughout the Canadian environment. It is relatively persistent, although it is lost through photo- and bio-degradation under some circumstances. The physico-chemical properties that determine the environmental fate of PCP vary with pH, so the expected extent of contamination will be dependent on specific site conditions. Environmental fate modelling (Fugacity Model Levels I and II) results predict that PCP becomes increasingly a water pollution problem with increasing pH, as less material is sorbed on to soil and sediments at neutral to high pH levels (7.0-8.5).

PCP is toxic to many forms of life, as it interrupts the process by which cells store energy as ATP. Fish bioconcentrate PCP and have been found containing 10,000 times the ambient water concentration in the Bay of Quinte. For mammals, the LD50 is approximately 150 mg/kg body weight, with lethal concentrations in human body fluids being between 20 and 190 ppm. Non-occupationally exposed people typically have levels of about 40 ppb, attributed to food chain contamination and direct exposure to treated wood.

Three studies of soil contamination by PCP around treated utility poles have found that the level of PCP in the top layer of soil decreases rapidly with distance from the pole. Possible explanations for this observation include:

1. Very little PCP leaches from the installed poles.
2. The PCP that leaves the poles does so in the first year or two following installation and is not detectable after that.
3. The soil PCP concentration is rapidly decreased by biodegradation.

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4. The soil PCP is transported away from the poles either in an immiscible oil phase or dissolved in water.

As long as PCP remains in the treated wood or in the immediately adjacent soil, protecting the wood from fungal attack, the concern for environmental contamination is minimal. PCP in soils will likely biodegrade over time. If PCP is not highly adsorbed at the site of application (eg, in neutral to alkaline soils of low organic content) contamination of surface or ground water becomes a possibility.

The following research areas have been identified as being significant to the goal of quantifying the extent of PCP migration, effects and persistence due to its use in utility poles.

1. Biodegradation rates of PCP under Canadian environmental conditions.

2. Leaching rates of PCP from treated wood under various pH rainfall regimes.

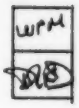
3. Adsorption of PCP to Canadian soils including partitioning between water/soil/oil phases in different pH conditions.

4. Toxicity of PCP leached from wood to aquatic organisms.

5. Survey of current extent of PCP contamination near poles of various ages in different soils.

6. Determination of the extent of PCP contamination of soils under pole storage yards.

7. Development of a clean-up/destruction method for out-of-service poles, in anticipation of increased disposal costs associated with current practices.



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To: DR. D. MILLS
Director of Research

ENVIRONMENTAL PERSISTENCE AND MIGRATION OF PENTACHLOROPHENOL, WOOD POLE PRESERVATIVE PART I: LITERATURE REVIEW

1.0 INTRODUCTION

The search for an acceptable wood pole preservative has been a concern of the electrical utilities for many years. The research to date, however, has focused on the effectiveness of the various treatments, while their behaviour in the environment has been given much less attention.

Pentachlorophenol (PCP) is the major treatment used by utility companies in Canada for the preservation of wood utility poles. Ontario Hydro has approximately 1.5 million wood poles, most of which have been full-length treated with a 5% oil solution of pentachlorophenol (PCP) prior to installation, and about a third of these have had a subsequent remedial ground-line treatment with a 10% pentachlorophenol grease. The preservative tends to migrate down the poles over time, and out into the surrounding soil, where it kills the organisms that cause decay in the wood. There is a general lack of information on the extent to which pentachlorophenol-based wood treatments leave the treated wood and travel through soils.

Low levels of PCP are now ubiquitous in the Canadian environment (Jones, 1984), and both federal and provincial regulators have been reviewing the status, and uses, of PCP. Ontario Hydro, anticipating possible challenges to the continued use of PCP as a pole preservative, has initiated a study into the potential for migration of PCP away from pole installations, and has installed test poles treated with alternative preservatives.

If the heavy-duty wood preservative uses of PCP are discontinued, it will likely be replaced, at least in the near future, with the widely used chromated copper arsenate (CCA). For transmission and distribution poles, where the hardening of the wood is a serious concern for the line-workers who must climb them, the CCA will be in a polyethylene glycol formulation (CCA-PEG), developed by Bell Northern Research. The addition of the waxy PEG maintains higher pole moisture levels. This formulation has been used by Bell Telephone on telephone poles for several years. In 1988, about 10% of the new poles purchased by Ontario Hydro were CCA-PEG treated. These are being evaluated, and a complete switch to CCA-PEG is not expected in the near future.

This report contains a literature review of the environmental contamination and toxicity of PCP, the degradation processes, results of fugacity modelling of PCP pathways (Level I and II), a review of the research to date on the migration of PCP from treated utility poles, and a summary of the research needs in this area.

2.0 LITERATURE REVIEW

2.1 Toxicity

PCP is toxic to many forms of life. In Canada, it is registered under the Pest Control Products Act, for use as a fungicide and as a bactericide. A number of regulatory and product management options are currently under review. In the U.S., the E.P.A. has registered PCP as a fungicide, bactericide, algicide, insecticide and as a disinfectant. U.S. pentachlorophenol products are in a "Restricted Use Category" and sales are restricted to certified applicators. U.S. labels for pentachlorophenol and related salts must warn of the potential fetotoxicity of the product (Pesticides Directorate, 1987).

Pentachlorophenol has limited water solubility (17 mg/L) while sodium pentachlorophenate is very water soluble (330,000 mg/L). The former is used in oil-based treatments for wood preservation, while the latter is used as a water-based surface application for wood protection. According to Williams (1982), "It should be noted that although the solubilities of PCP and its sodium salt differ, their toxic effects are basically the same: therefore (for practical purposes) the data pertain to both compounds."

Schultz (1987) tested 21 phenols for their mode of action against bacteria. He found that the octanol-water partition coefficient (Kow) and the acid dissociation constant (Ka) were significant variables. (Kow is the ratio of the equilibrium concentrations in octanol and water). Phenols with pKa (negative logarithm of Ka) values over 8 acted as polar narcotics, while those with Ka less than 6.5 (including PCP) were uncouplers of oxidative phosphorylation. The relationship between these variables was determined to be

$$\log(BR) = \log(1/IGC50) = 0.5671 (\log Kow) - 0.1885\ pKa + 0.8190$$

where BR is the biological response, equivalent to the inverse of the IGC50, the 50% inhibitory growth factor.

The effects of chlorophenols on plant mitochondria were studied by Ravenel et al (1985) and Ravenel and Tissut (1986). They found that pentachlorophenol was a powerful uncoupler of oxidative phosphorylation, the process by which chemical energy is stored in the form of ATP, in cells. In comparing the effect of PCP on plant mitochondria to its effect on animal cells, they noted that, although PCP has about 10-fold greater activity than any other compound in uncoupling phosphorylation in the guppy, its activity in plant mitochondria is about the same as that of 2,4,5- or 2,3,6-trichlorophenol.

Algae of various species were studied by Smith et al (1987) for toxic effects of PCP. They found a range of 96 h EC50 values from 0.08 to 7.0 mg/L. The toxicity was due primarily to the concentration of the undissociated species. For algae the relationship was determined to be

$$\log(EC50) = 0.847\ pH - 4.28$$

for a pH range of 7.3 to 8.6. The probable explanation for the pH dependence of toxicity is that as the pH decreases, the octanol-water partition coefficient decreases, and the phenol form partitions to a greater extent in the lipid fraction of the aquatic biota.

Crossland and Wolff (1985) studied PCP toxicity in experimental outdoor ponds. At concentrations of PCP of 50 - 100 µg/L in water of pH 7.3 - 10.3 (mean 8.4) they found no evidence of direct effects on zooplankton, or fish growth and survival. A toxic effect on filamentous algae, however,

resulted in decreased levels of dissolved oxygen as the algae decayed, which led to the death of rainbow trout. Their findings of indirect effects of PCP on an experimental ecosystem illustrate the unpredictability of toxicity from single-species laboratory tests.

Choi and Aomine (1972) investigated PCP as a herbicide, and the effects of soil on the herbicidal action of PCP. They found that while adding soil to an aqueous PCP solution does decrease the PCP concentration in that solution, the adsorbed and/or precipitated PCP retained some of the toxicity to the plant. As the mechanism of PCP adsorption by the soil varies with the soil type, the toxicity would not be the same for all soils. The organic content of the soil and the soil acidity were found to be the significant soil properties. The higher the pH of the soil suspension, the greater the toxicity. In general, PCP in acid soils was found to be less active and more persistent than in neutral soils.

Stuart and Robertson (1985) studied the acute toxicity of PCP, both technical grade and pure (99%) PCP, to the freshwater snail. They found a significantly greater toxicity from the technical grade, and concluded that the impurities were more toxic than the PCP itself. They also compared the toxicity in the light to the toxicity in the dark, to determine the effects of photodegradation and found that the LC50 (lowest concentration for 50% mortality) for a four-hour exposure to laboratory light was 100 µM for tests conducted in the dark. This indicated that the concentration of PCP is reduced by the presence of light and that the photodegradation products are less toxic than the PCP.

One unexpected result was that snails harvested in the Spring showed a much greater sensitivity to PCP than did those collected in the Fall. The proposed explanation for this phenomenon was that the better nutritional status of the Fall snails gave them added resistance to PCP. In general, the LC50 for a four-hour exposure of Fall snails was about 100 µM PCP (27 mg/L) while a 96-hour exposure test gave an LC50 of 1.1 µM PCP (0.3 mg/L).

The toxic effects of PCP are much greater for aquatic biota than for terrestrial biota. Large doses of PCP resulting from accidental spills or improper disposal have been known to kill fish, which bioconcentrate pentachlorophenol. Fox and Joshi (1984) found that fish in the Bay of Quinte had PCP levels 10,000 times that found in the water. Concentrations of 0.2 ppm may be toxic to certain species of fish, with salmon being one of the most sensitive. The toxicity of PCP is increased by lowering the pH of the water (Arsenault, 1976).

The authors of a National Research Council report (1982) concluded that, for a spectrum of mammalian species, the LD50 is remarkably constant at 150 mg/kg body weight. The sublethal effects in animals include rapid breathing and lipid loss, as the organism alters its metabolism to satisfy its energy requirements. A series of toxicity studies involving various organisms is contained in the monograph on pentachlorophenol edited by K. Ranga Rao (1978).

Pigs and poultry have been killed by exposure to PCP absorbed from wood shavings used as bedding material (USDA, 1982). Studies of the chronic toxicity of both technical grade and pure PCP to young cattle reported by Jones (1984) showed clearly that the toxicity of PCP was related to its impurities, including lower chlorinated phenols, polychlorinated dioxins and furans and chlorobenzenes. Fetotoxicity in rats, however, was determined to be greater from purified PCP than from the less pure commercial grade. The maternal dose leading to 50% lethality in embryos was 16 mg/kg purified PCP vs 44 mg/kg commercial grade PCP. The explanation for this seeming anomaly given by the authors of the NRC report was that the PCDD contaminants induce the enzyme system which degrades PCP, and, in the absence of this induction, more PCP reaches the target sites, leading to greater toxicity. Thus PCP is thought to be the primary acute fetotoxic agent in commercial-grade PCP.

Williams (1982) reviewed the occupational hazards of PCP and summarized his conclusions as follows: (1) toxicity of PCP itself was of greater concern than that of the contaminants; (2) the hexachlorodibenzeno-p-dioxin (HCDD) contaminant does cause chloracne in the concentrations present in technical PCP; (3) PCP is embryotoxic and teratogenic; and (4) technical PCP may cause long-term liver damage. He also noted that no safe level for the exposure of pregnant women to PCP could be established at that time.

Information on the dioxin and furan content of current production of pentachlorophenol was obtained from Vulcan Chemicals (D. Lindsay, pers. comm.). The dioxin of most concern, 2,3,7,8-TCDD, has not been found using detection methods with a 1 ppb limit. Other tetra-isomers have not been detected at the 50 ppb level. Penta-isomers of dioxins and furans are both detectable at about 10 ppb. For HCDD, analyses are performed on every batch of pentachlorophenol produced, and current levels are averaging about 1.5 ppm, an order of magnitude less than was found three years ago. (In February 1989, the regulatory requirement will be 2 ppm average, with an allowable 4 ppm maximum.) The corresponding furan is found at levels around 8 ppm. The average H7CDD content is about 80 ppm, and the corresponding furan content 75 ppm.

There have been human deaths from exposure to PCP. Robson et al (1969, cited by Jones, 1981) reviewed the literature on poisonings from ingestion or adsorption of PCP. In one case, children in a St. Louis hospital nursery were poisoned when PCP was mixed in with the detergent used to wash their diapers and bedding. Most poisonings, however, occur due to occupational exposure. Workers using products containing PCP have elevated PCP levels in blood and urine, but the significance of these levels is unclear. In Canada, one worker has died from exposure to PCP while dipping wood in a treating solution with bare hands (Arsenault, 1976). Lethal concentrations of PCP in human biofluids ranged from 20 - 190 ppm, while normal levels in nonoccupationally exposed people are about 40 ppb. This is attributed to food chain contamination and direct contact with PCP-treated wood (Dougherty, 1978).

A recent Agriculture Canada Discussion Document on Pentachlorophenol (Pesticides Directorate, 1987) stated that "Information based on human epidemiologic studies suggests that some increased risk from certain forms of cancer may result from occupational exposure to higher levels of chlorophenol compounds. Precise scientific information documenting the significance of extremely low levels of chlorophenols and their impurities in the general population, and in food and drinking water is not available..."

2.2 Environmental Contamination

The behaviour of a contaminant in the environment is dependent on its physico-chemical properties and the properties of the environment to which it is released.

The aqueous solubility of PCP increases exponentially with pH (Choi and Aomine, 1974). Pentachlorophenol is a weak acid with a pKa value given by Schellenberg et al (1984) as between 4.75 and 5.25 depending on the method of determination. (5.0 was used in this work). The solid phase vapour pressure is 0.015 Pa (Verschueren, 1983). Only the undissociated PCP has any vapour pressure.

The octanol-water partition coefficient, Kow, of PCP varies with pH. Kaiser and Valdmanis (1982) found that PCP exhibits very different "apparent Kow" values over the range of pH that exists in natural waters, and therefore, predictions of overall distribution coefficients based on simple partitioning of the non-ionized forms will be in error. Not surprisingly, the bioaccumulation factors found by different researchers, working with different water systems, vary by orders of magnitude (Jones, 1984). Bioaccumulation has been found to be directly related to Kow for most organic

pesticides (Mackay, 1982) although Swackhamer and Hites (1988) found the correlation to be weak for fish in a natural, as opposed to laboratory, environment.

Some PCP enters the atmosphere by volatilization from the surfaces of natural waters but the major route for transport is likely to be via particulate matter. Vapour phase PCP will preferentially sorb onto small airborne particles due to its relatively low vapour pressure. Also, it can recrystallize on the surface of treated wood (blooming), brush off, and form aerosols. (USDA, 1981). Jones (1984) reported the results of a study by Cautreels et al (1977) in which the organic fraction of the airborne particulate matter was analyzed. Above La Paz, Bolivia, at 5200 m elevation, the concentration of PCP was 0.25 - 0.93 $\mu g/1000\ m^3$, while residential areas of Antwerp, Belgium, had PCP concentrations of 5.7 - 7.8 $\mu g/1000\ m^3$. PCP has been found in rainwater and snowmelt in many locations. Fish taken from Siskiwit Lake, a pristine lake on Isle Royale in northern Lake Superior, were found to contain a number of pesticides and their precursors or degradation products, including pentachloroanisole, a breakdown product of PCP (Swackhamer and Hites, 1988). It was thought that these could only have arrived in the lake from atmospheric deposition, as the island has been a national park since 1940 and has seen little anthropogenic activity.

Wood preservation accounts for almost all of the uses of PCP in North America. Approximately 1200 metric tonnes are imported to Canada annually for the pressure-treatment of poles and other industrial commodities (Pesticides Directorate, 1987). Problems may arise if PCP is leached from treated wood, and from accidental releases to the ground, particularly when the PCP leaves the immediate area and migrates through the soil and into surface or ground water. There have been numerous studies of PCP contamination of soil, ground water and surface water from wood-preserving facilities (Fox and Joshi, 1984; Kitunen et al, 1987; Goerlitz et al 1985; Patterson and Liebscher, 1987) and from chemical waste dumps (Johnson et al, 1985).

The technical grade PCP used for wood preservation is about 86% pure, the other components being tetrachlorophenols, trichlorophenols, hexachlorobenzene and various chlorinated dioxins and furans (USDA, 1982). Czuczwa and Hites (1986) found that the most likely source of polychlorinated dioxins and furans in Lake Ontario surface sediments was PCP production.

Choi and Aomine (1974a, 1974b) elucidated the effects of pH on PCP adsorption, finding that adsorption occurs to a greater extent on strongly acidic soils than on moderately acidic soils, regardless of clay mineral or organic matter content. They found no adsorption on slightly acidic or neutral soils. They conducted experiments designed to separate the mechanisms of losses from aqueous PCP solution when various amounts of soils are added. The solution concentrations ranged from 12.5 to 500 mg/L. Below pH 5.0, PCP precipitated from soil solution according to the solubility of PCP at the prevailing pH. Above pH 5.4, the solution concentration decreased as clay was added, indicating adsorption to clay particles was occurring. In desorption experiments, the precipitated PCP dissolved readily when saturated soil was washed with deionized water, and the clay-adsorbed PCP was also released, but at a much lower rate.

Banerji et al (1986) conducted a number of experiments to assess the potential for pentachlorophenol migration into ground water, at PCP concentrations likely to be found in contaminated aquifer systems (<10 mg/L). They concluded, from their experimental results, that soil organic content and pH were equally important properties governing the extent of adsorption, that adsorption increases significantly with decreasing pH, and that adsorption to soils is largely reversible. The significance of the last result is that while PCP will be initially retained on the soil to a large extent, it will slowly be released to ground water when water of a lower concentration passes through the contamination zone.

Patterson and Liebscher (1987) found that the retardation factor (the ratio of the velocity of the ground water to the velocity of the contaminant plume) for a spilled pentachlorophenol/phenate solution flowing through an unconfined alluvial aquifer was between 1.05 and 1.43. The organic content was very low, about 0.01%. In 1978, about 18,000 L of a 7500 mg/L solution had leaked from a sawmill dip tank located approximately 120 m from the Okanagan River. A purging operation, flushing a total of about four pore volumes of water through the aquifer, recovered about 40% of the chlorophenate, leaving 1-2 mg/L phenol/phenate in the recovered water, at a pH of about 6.6. By 1984, the water concentration in the aquifer had only fallen to 0.35 mg/L. In the intervening time, an estimated 35 pore volumes of water had passed through the contaminated zone. The proposed explanation for the long recovery time was that when the alkaline dip solution met the slightly acidic ground water, the drop in pH caused the pentachlorophenol to precipitate out of solution. The residual contamination in 1984 was due to the slow dissolution of this precipitate back into the ground water.

Effluent from the Northern Wood Preservers Ltd wood treating facility in Thunder Bay had, by 1978, contaminated the surrounding land area and the adjacent waters of Lake Superior during 40 years of operation. The treatments used included creosote, pentachlorophenol and chromated copper arsenate (CCA). The majority of the lake contaminants infiltrated the landfill underlying the site and moved laterally into the lake (Thompson et al, 1978). During a clean-up operation in 1978, lake sediments were dredged and pumping wells installed between the site and the lake. The groundwater pumped from these wells contained 2-3 g/m^3 PCP. Ontario specifies a limit of 0.5 ppb, or 0.0005 g/m^3 PCP, residue in receiving waters (G. Cutten, Ontario Ministry of the Environment, pers. comm.). The effluent from these wells needed treatment before being discharged to a surface water body or municipal sewer. The taste threshold is about 30 ppb (D. Lindsay, pers. comm.).

Fox and Joshi (1984) studied the distribution of PCP in the Bay of Quinte, Lake Ontario, where a wood preserving plant has operated on the banks of the bay since the 1940s. There was very little effluent from the treatment process containing PCP, but the stored, treated lumber released a significant amount, giving concentrations in the river several hundred times higher than similar areas without treatment plants. Sediments are a sink for PCP and its photodegradation products. Fox and Joshi found that the ratio of these species remained unchanged over decades of burial, indicating that further degradation did not occur in the sediments.

2.3 Natural and Enhanced Degradation

2.3.1 Photodegradation

Pentachlorophenol photodegrades readily in the presence of water. The rate depends on latitude, time of day, time of year and light intensity, as well as on the pH and turbidity of the water (NRC, 1982). Photolysis is highly depth-dependent, with values of rate constants reported on a "cm/day" basis. For example, estimated rate constants for photolysis at 45° North latitude, in the month of June were 17.2 and 0.15 cm/day, for pH of 7 and 3-4 respectively. For the month of December, the estimated rate constants were 3.25 and 0.014 cm/day. The corresponding half-lives are 57 min and 4.6 days at pH 7 and 3-4, respectively in June, and 5.1 h and 49.5 days for pH 7 and 3-4, respectively in December. Wong and Crosby (1978) studied photodegradation in glass containers exposed to UV light. They found that the rates of photolysis at pH 3 and pH 7 were 5.2×10^{-7} and 2.7×10^{-5} per second respectively. Increased acidity prolongs the persistence of PCP. They identified the photodegradation products as lower chlorinated phenols, tetrachlorodihydroxyl benzenes and non-aromatics such as dichloromaleic acid. Prolonged irradiation of PCP and its degradation products resulted in colorless solutions containing no ether-extractable volatiles.

Octachlorodibenzo-p-dioxin was formed when high concentrations of sodium pentachlorophenate were irradiated.

Hwang et al (1986) studied the photodegradation rates of chlorophenols in estuarine waters. They found the rate constant for PCP at a depth of 3.0 cm to be 0.37 h^{-1}, giving a half-life of about 2 hours. They determined that below 20 cm depth, photolysis would proceed very slowly, due to the attenuation of light by dissolved and particulate substances. Hwang et al (1987) found that at a pH below the pKa value, rates of photolysis for phenols in estuarine waters are much lower because the phenoxide ion photodegrades more readily than the non-ionized form. They also found that lower photolysis rates of PCP in estuarine water than in distilled water were due to the inhibition of photolysis by chloride ions.

Pignatello et al (1983) studied the disappearance of PCP from artificial freshwater streams. Glass vials containing water supplied by the Mississippi River which had known quantities of PCP added, were suspended at various depths and the PCP concentration measured after either 3 or 24 h. The observed rate constants decreased from 0.996 h^{-1} at 0.5 cm depth to 0.072 h^{-1} at 13.8 cm depth, for the 3-h mid-day tests. The corresponding 24-h test results were 0.229 at 0.5 cm and 0.016 at 13.8 cm. Below 13.8 cm the rates were too slow to obtain accurate values of the rate constants.

2.3.2 Biodegradation

Smith and Novak (1987) conducted microcosm studies using Pennsylvania and Virginia soils from depth up to 31 m. All soils contained significant (10^5 to 10^7 per gram) microbial populations. The ground water pH at both sites was around 4.6. The soils from saturated zones showed lower rates of biodegradation than soils from unsaturated zones. The authors expressed uncertainty over whether the sorbed fractions of phenolic contaminants would be subject to biodegradation. They suggested that as the aqueous concentration decreases due to biodegradation, some sorbed phenolic compounds may desorb to restore equilibrium and thus be available for degradation. Equilibrium concentrations of PCP, as high as 25 mg/L, were reduced to non-detectable levels within 3 months. They warned that the biodegradation rates determined by them should not be extrapolated to high concentrations that might inhibit microbial action, or to sites which may contain more than one potentially toxic compound.

Field studies of PCP degrading microorganisms by Watanabe (1977) showed that within 6 weeks of an initial application of PCP, the concentration of PCP degraders increased by 3 orders of magnitude (from 10^2 to 10^5 per gram).

Kuwatsuka and Igarashi (1975) studied the influence of soil properties on the degradation of PCP. They found a strongly positive correlation between the rate of degradation and the organic matter content, and a slight positive correlation with clay mineral content, free iron content, phosphate absorption coefficient and cation exchange capacity. It was only very slightly (if at all) correlated with texture, clay content, degree of base saturation, soil pH (natural levels, range: 4.6 to 6.4) or available phosphorus content.

Martinson et al (1986) isolated a naturally occurring microorganism from Mississippi River water that was able to degrade PCP to CO_2, H_2O and chloride ions, utilizing PCP as a sole carbon source for growth. They investigated the effects of soil moisture content, soil type (sandy and loam), temperature and PCP concentration. Soils containing 15% and 20% (wt/wt) water content had the greatest rate and amount of PCP removal. At 50% water content, no PCP mineralization was seen for 10 days but then the degradation rate proceeded at a very rapid rate and over an extended time period, the same amount of PCP was degraded as in the drier soils. Sandy soils had the slowest

mineralization rates and loam the fastest. Optimal temperatures were between 24 and 35°C, while virtually no mineralization occurred at 12 or 40°C. Soil concentrations of PCP had a significant effect on mineralization rate, with concentrations less than 100 ppm being degraded in less than one week, while no degradation occurred at concentrations in excess of 500 ppm.

Pignatello et al (1983) studied the contributions to biodegradation made by the various compartments in artificial freshwater streams. They found that photolysis was rapid at the surface but decreased markedly with depth, and that adsorption, sedimentation and volatilization of PCP were not significant mechanisms of removal. Microbial degradation, after an acclimatization period, was the most significant removal mechanism. Of the places within the stream, the surface areas such as rocks and vascular plants and detritus particles, and the surface sediments, were the locations of most of the degrading microorganisms.

Pignatello et al (1985) found that PCP loss in the stream was in the range of 55% to 74% due to microbial degradation, after an adaptation period. Epilithic (rock-attached) microbes were most significant, followed by epiphytic (plant-attached), followed by sediment and free-floating microbes. Uptake by aquatic plants was also determined to be an important PCP removal mechanism. Pignatello et al (1986) cautioned against extrapolating biodegradation rates from artificial situations to natural systems for the following reasons:

1. Biodegradation requires an adaptation period on the order of weeks. Spills into unadapted waters may be diluted before adapted populations can begin to degrade the contaminants.

2. Degradation is mainly accomplished by organisms attached to surfaces, the rate of degradation in real steams will be dependent on the ratio of water volume to surface area.

3. Degradation occurs very slowly at temperatures below 10°C.

4. There may be a lower threshold concentration of PCP for adaptation to occur.

A number of studies have been conducted with various isolated strains of PCP-degrading bacteria. Trevors (1983) isolated from agricultural soils and streams three species of Pseudomonas near Guelph, ON. Stanlake and Finn (1982) collected soil samples from gardens and around treated utility poles, from streams and sewage treatment plants, in New York State. They found PCP-degrading bacteria of the genus Arthrobacter in all four habitats, although the concentrations in each were not given. They also found that increasing the pH from 6.8 to 7.8 decreased the length of the lag phase for bacterial growth.

Edgehill and Finn (1983) attempted to use the Arthrobacter bacteria to enhance degradation in garden soil treated with known quantities of PCP. The soil-water concentrations used were 120 to 150 mg/L, which was not sufficient to poison the culture. A half-life of one day was determined for test soils incubated at 30°C, while uninocculated soils showed half-lives of 12 to 14 days. Soils kept in an outdoor shed at average daily temperatures of 8 to 16°C had much slower rates of PCP disappearance.

PCP-contaminated soils from three geographic areas of Minnesota were found to contain several strains of Flavobacterium that degrade pentachlorophenol (Saber and Crawford, 1985). Two areas sampled did not yield PCP-degrading microorganisms, and the explanations offered by the authors were that in one case the soil was sandy with very low moisture content and only three weeks exposure to PCP, while the other site had very high levels of contamination (5.6×10^6 mg/kg) that were likely toxic to bacteria.

Biodegradation rates for soil and sediment are very difficult to establish from the literature, for Canadian climatic conditions. In general, the rate of degradation increases with temperature, is faster under aerobic than anaerobic conditions, is very dependent on the number of locally adapted microbes, is strongly influenced by pH, depends on formulation, soil type, organic and moisture contents and depends on sediment redox potential (Jones, 1984; Pignatello et al, 1986; DeLaune et al, 1983; Kaufman, 1978). Part of the difficulty in establishing the natural degradation rates stems from the problems encountered in extrapolating laboratory results to field situations (Kirsch and Etzel, 1973). Estimates of these rates for acid, neutral and basic environmental conditions (pH 5.5, 7.0 and 8.5 respectively) are required, however, for "fugacity" modelling, described in the next section. Baker et al (1980) found that PCP in soils was slow to degrade, requiring 8-160 days for a 70% decrease in soil concentration for an aerobic soil at pH 7.1. As the fractions of PCP dissociated at pH 7.0 and 8.5 are about 99 and 99.97%, respectively, degradation rates will likely not vary much in this range. At pH 5.5, however, the amount dissociated is 76% so there will likely be a significant decrease in biodegradation rates at the lower pH level.

For sediments, DeLaune et al (1983) found the half-life of PCP to be 19 days at pH 8.5 in a Northern US setting. Jones (1984) reported a value of 80 days for pH 3.5-5.5. The half-life at pH 7.0 was estimated to be some intermediate value; 45 days was chosen for use in the model. Microbial degradation in the water column has not been reported and is assumed to be zero.

3.0 FUGACITY MODEL

3.1 Model Descriptions

An understanding of the environmental behaviour of pentachlorophenol is necessary to allow predictions to be made regarding the extent of the preservative migration under various environmental conditions. One of the best and most widely accepted approaches to studying environmental pathways of chemical contaminants is through the use of fugacity models. (Fugacity has units of pressure, and can be viewed as the "escaping tendency" of a chemical). These models are based on the concept that differences in the fugacity of a chemical species between environmental compartments (eg, air, water, soil, sediments, and biota) drives the transport of the chemical from compartments of high fugacity to those of low fugacity, until equilibrium is reached, and fugacities in all compartments are equal. The concentration of the chemical in a given compartment, C, is the product of the fugacity, f, and the fugacity capacity, Z, ie, $C = Zf$. Each compartment has a fugacity capacity for a given chemical, which depends on the chemical's properties of vapour pressure, aqueous solubility and octanol-water partition coefficient (Kow). Details of the models are given in Mackay and Paterson (1981 and 1982).

For Level I calculations, the conditions are those of equilibrium, steady-state, and no flow. For Level II, they are also those of equilibrium and steady-state, but advection and reactions of the chemical within the system are considered. The variable values chosen for the model simulations, and the explanation of the choices, are described in Mortimer (1988b).

3.2 Model Predictions

Level I Fugacity Model

For a Level I (equilibrium, steady-state) calculation, the primary media for partitioning change with pH. For all pH levels examined, the three most contaminated compartments are water, soil and sediment. For a system pH of 5.5, most of the PCP is found sorbed to the soil and sediments. At a pH of 7.0 (at which 99% of the PCP is in the dissociated, or phenate form) more than 2/3 of the PCP is in the water, and at a pH of 8.5, more than 80% is in the water. Pentachlorophenol

becomes increasingly a water pollution problem with increasing pH because the material has a much higher water solubility, and a correspondingly lower affinity for soil and sediments, at higher pH levels.

Level II Fugacity Model

The amount of PCP in each environmental compartment is predicted to be almost the same as that predicted by the level I model. As the pH increases, the PCP increasingly is found in the water phase, so the loss attributable to advection in the water phase increases, while advection in the air phase shows the opposite trend, decreasing as pH increases. Air contributions to the advection total are small, however, and the overall advection loss shows an increase with increasing pH. What is "lost", however, by advection from one defined area is gained by another.

Due to increasing water concentrations as pH increases, the fraction of PCP in the system lost through photodegradation increases, even though the photodegradation rate constant decreases with pH. The fraction of PCP degraded by sunlight is predicted to be about 10% at pH 5.5, increasing to about 16% at pH 8.5.

Biodegradation in sediment consumes a larger fraction of PCP than does biodegradation in soil for pH 5.5 and 8.5 but the opposite is predicted for pH 7.0. This is due to two counter-acting trends. The octanol-water partition coefficient is greater at low pH and sediments, in this model, have twice the organic matter content as soil, so at pH 5.5, the sediment PCP concentration is four times that predicted at higher pH levels. Therefore, the amount of PCP available for sediment-phase biodegradation is greater. At higher pH levels, however, the biodegradation rates are greater, resulting in a faster breakdown of PCP, but with a lower concentration of substrate.

The overall residence time of PCP in the "evaluative environment" of the model decreases from 145 days at pH 5.5 to 78 days at pH 7.0 to 69 days at pH 8.5. This does incorporate system losses through advection, however, which results in PCP simply leaving the confines of the environment in question and moving somewhere else. The implication of this is that neutral to alkaline conditions have a greater potential for aqueous phase migration of PCP than acidic conditions in which PCP is more persistent in soil and sediments.

To obtain an estimate of the persistence of PCP in the "total" environment, the residence time should be calculated as that due to bio- and photo-degradation only. In that case, the residence times predicted by the model, for pH 5.5, 7.0 and 8.5 are 301, 163 and 154 days, respectively. These numbers are for an "evaluative environment" of average parameter values; actual environmental persistence in any real situation will depend on the local environmental conditions.

4.0 STUDIES OF THE MIGRATION OF PENTACHLOROPHENOL FROM TREATED WOOD POLES

4.1 US Study

A study of the fate of PCP in soils was reported by Arsenault (1976). Soil samples were taken from around the bases of PCP-treated poles in various geographical areas. The samples were collected at distances of 1, 12 and 60 in. from the poles in each cardinal direction, to a depth of six in. from the ground surface. The age of the poles and the soil pH were not reported. The results of this study are listed in Table 1.

TABLE 1

STUDY RESULTS REPORTED BY ARSENAULT (1976) ON PENTACHLOROPHENOL CONTENT OF SOILS ADJACENT TO TREATED WOOD POLES. COMPOSITE N-E-S-W SAMPLES, PCP CONCENTRATION IN MG PCP/KG SOIL (PPM)
NOT GIVEN: AGE OF POLE, pH OF SOIL

		Distance from Poles		
Pole Location	Soil Type	1 in	12 in	60 in
Jackson, Tennessee	sandy, silty clay	1.4/0.8	0.13	0.04
		0.3/0.15	0.05	0.04
		120/320	3.1/1.6	0.81
Savannah, Georgia	sandy, well-drained	6200/320	0.08	0.04
		1.9/20	0.05	0.03
		1200	29	0.18
Spartonburg, South Carolina	clay-loam	260	1.7	0.5
		300	0.34	0.09
		50	1.5	0.08
		14	0.78	0.24
		34	3.4	0.11
Gresham, Oregon	loam	380	0.42	0.30
		5200	40	0.40
		9500	1.4	0.20
Selma, Alabama	sandy, loam	7.4	0.94	1.0
		4.8	2.2	0.48
		32	0.88	0.30

Average PCP concentrations at the pole (1 in.) were 658 ppm with a maximum of 9500 ppm. At 12 in. the average concentration was 3.4 ppm with a maximum of 450 ppm. At 60 in. the average concentration was 0.26 ppm with background concentrations reported to be 0.2-0.4 ppm. Jones (1981) reported that the background levels found in this study were very high and that some other explanation such as reagent contamination would be more plausible. Arsenault concluded that the results indicate that either degradation of PCP by the soil or a lack of migration into the soil was occurring. He later stated that "...the argument could be made that PCP has percolated through the soil into layers below the six-in. zone sampled and into the ground water and, therefore, was non-detectable in our sampling." However, he dismissed this argument by citing laboratory evidence of biodegradation. As detailed in the above section on biodegradation, this may not be applicable to, or provide adequate detoxification for, many sites.

For PCP-contaminated soils in Canada, we could expect biodegradation to remove PCP for the months of the year when the average temperature is above 10°C. In many situations, the natural microbial populations will likely contain sufficient pentachlorophenol degraders that, given an appropriate adaptation period, a substantial amount of PCP contamination will be destroyed. This

may occur either without intervention, or with only nutrient addition, depending on the local conditions. Enhanced biodegradation methods, such as flushing soil with an alkaline fluid and treating the effluent in a bioreactor to remove PCP, may be necessary to clean up areas of high concentration.

4.2 Nova Scotia Study

In 1983, the Nova Scotia Power Corporation began a three-year field study, described in Report No. 83-EP-2, to determine the extent of migration of PCP from poles which had been ground-line retreated with 10% Penta grease, using the spade-injection method. They report that about 0.43 kg of PCP was applied to each pole. The test poles consisted of two poles from each of three retreatment years, 1981, 1982 and 1983. Soil samples were taken at distances up to 6.0 m from the poles at depths of 0.15, 0.30 and 0.45 m. The results of the soil analyses are in Table 2. From these results, author T.P. Toner concluded that there was limited migration of PCP from the poles out to a distance of six metres, the concentration of PCP around the test poles did not show any clear trends with depth of soil, that the PCP concentration decreased rapidly with distance from the poles and that, close to the pole, the concentration of PCP in soil increases with time elapsed since retreatment, while the opposite occurs at distances greater than 2.5 m from the poles. Neither the background levels of PCP in the soil at greater distances from the poles, nor the analytical detection limits were provided.

Arsenault (1976) found that the soil concentrations were down to background levels within 12 to 60 in. (0.3 to 1.5 m) of the pole, as discussed above. An alternate hypothesis to explain the Nova Scotia results is that the levels of pentachlorophenol in the soil at distances greater than one metre are "background" levels. To test this hypothesis, a statistical analysis of the data was conducted.

As can be seen in the Table 2, the data are somewhat sparse, and there is much variation between replicate samples. Of the four variables, site, years elapsed since treatment, distance from the pole and soil depth, the first two were found to be marginally significant, the third is significant and the fourth is not significant. The number of years elapsed since treatment shows a slight negative correlation with concentration for one metre and five metres distant from the pole, and a slight positive correlation for three metres distant. (Two, four and six metre data were not analyzed due to lack of data.) Since these trends were inconsistent, and the significance of the trends was slight, the data were pooled for this variable, as well as for site and soil depth. The only significantly different distance was found with the one metre data; the distances of two to six metres were not significant, so these values were pooled for further analysis.

The data were transformed to the natural logarithm of the concentration data, to eliminate the skewness common to concentration data. For distances of two to six metres from the poles, the overall average (log-mean) soil PCP concentration of 0.046 mg PCP/kg soil (95% confidence interval = 0.038 - 0.056 mg/kg) is an estimate of the general background levels of PCP in these Nova Scotia soils, and is likely to be unaffected by the ground-line retreatment of the nearby poles. By comparison, Arsenault (1976) reported background levels of 0.2 to 0.4 ppm PCP (mg PCP/kg dry soil) in soils that had not been exposed to PCP, although this value is somewhat suspect, as discussed earlier.

The average soil PCP concentration at one metre from the poles was significantly different from that found at greater distances. The higher concentrations at a distance of one metre from the poles than at greater distances are consistent with the results presented by Arsenault (1976). Occasional high concentrations found at greater distances could be due to localized contamination occurring at the time of pole retreatment.

TABLE 2

NOVA SCOTIA POWER CORPORATION (NSPC) STUDY RESULTS. PENTACHLOROPHENOL CONCENTRATION IN SOILS SURROUNDING GROUNDLINE RETREATED WOOD POLES, MG PCP/KG DRY SOIL (PPM)

			Distance from Poles (m)					
Site Number	Depth (m)	Years Elapsed	1.0	2.0	3.0	4.0	5.0	6.0
1	0.15	2	0.057		0.027			
	0.15	2			0.027			
	0.15	2			0.310			
	0.15	3			0.056		0.090	
	0.15	3			0.315			
	0.15	4	0.844				0.045	
	0.15	4	0.251				0.260	
	0.30	2	0.480					
	0.30	3	1.360		0.036		0.046	
	0.30	3			0.036			
	0.30	4	0.294				0.039	
2	0.15	2	3.700		0.028		0.038	
	0.15	2	0.220					
	0.15	3	0.440	0.047	0.095	0.031	0.027	
	0.15	3		0.061		0.233		
	0.15	4	0.025				0.039	
	0.15	4	0.026				0.023	
	0.30	2			0.014			
	0.30	2			0.019			
	0.30	3						
	0.30	4						
3	0.15	1	1.700		0.043			0.120
	0.15	1			0.044			
	0.15	2	0.063	0.066	0.344	0.128		
	0.30	3	0.048				0.026	
	0.30	3					0.023	
	0.30	1			0.041			
	0.30	1			0.034			
	0.30	2	0.163	0.035	0.260			
	0.30	3	0.070					
	0.30	3	0.093					
4	0.15	1	0.069		0.017			
	0.15	1			0.045			0.023
	0.15	2	0.098		0.023			
	0.15	2			0.034			
	0.15	3	0.060				0.021	
	0.15	3					0.029	

	0.30	1			0.035		
	0.30	1			0.006		
	0.30	2	0.140		0.021		0.097
	0.30	2			0.021		
	0.30	3	0.023				
	0.30	3	0.049				
5	0.15	0					
	0.15	1	6.0770		0.097		0.115
	0.15	1			0.064		
	0.15	2	1.424				0.022
	0.15	2	0.110				
	0.30	0	0.415	0.046		0.023	0.069
	0.30	0		0.044			
	0.30	1	1.940				
	0.30	1			0.109		
	0.30	2	1.615		0.091		0.017
6	0.15	1	0.118				0.081
	0.15	1					
	0.30	2	0.023				0.009
	0.30	2	0.009				
	0.30	0	0.044	0.059		0.045	0.037
	0.30	0		0.062			
	0.30	1	0.146		0.155		
	0.30	1			0.119		
	0.30	2	0.019				0.010
8	0.15	1	0.084		0.025		0.024
	0.15	1	1.326				0.128
	0.30	1	0.097		0.016		0.038
	0.30	1	0.456				0.026

Summary Statistics Calculated from NSPC Data

Distance from Pole (m)	Log-Mean Conc. mg/kg	Number of Samples	Maximum Conc. mg/kg	Minimum Conc. mg/kg	95% Confidence Interval
1	0.168	40	6.070	0.009	0.10-0.27
2	0.051	8	0.066	0.035	0.04-0.06
3	0.050	35	0.344	0.006	0.04-0.07
4	0.062	5	0.233	0.023	0.03-0.13
5	0.038	27	0.260	0.009	0.03-0.05
6	0.052	2	0.120	0.023	-
grouped 2 to 6	0.046	77	0.344	0.006	0.04-0.06

According to the Nova Scotia report, the soils of Nova Scotia are acidic, although the pH was not reported. Under these conditions, the PCP will be present in both the dissociated and undissociated forms. The former will tend to sorb to organic matter in the soils, very close to the pole from which it leached, while the undissociated form will likely be flushed from the soil relatively quickly.

4.3 British Columbia Study

A report on the British Columbia Hydro Project 7154-82 (1984) describes a study conducted to determine whether PCP migrates from poles which had been groundline retreated. The treatment used by B.C. Hydro differs from that used by Ontario Hydro in many respects. B.C. Hydro uses a formulation of 15% sodium borate (0.1 N aqueous solution pH = 9.2), 10% PCP, 15% creosote, and the remaining 60% is a grease carrier. This solution is applied to a 60 cm x 120 cm sheet of polyethylene-coated Kraft paper, in a layer 6 mm thick. This bandage is wrapped around a pole which has been excavated to a depth of 60 cm. The bandage extends slightly above ground level (2 cm), and the excavation is backfilled with the original soil. In the 1984 study, soil samples were taken around four poles, two of which had been similarly retreated 12 years previous (poles #1 and #2) and two of which had never been retreated (poles #3 and #4). Samples were taken at depths of 10 cm, 50 cm and 100 cm from the soil surface, at distances of 10 cm, 50 cm and 100 cm from the poles. The first samples were taken one week before treatment, then at 0, 3, 6, 9, 18, 25, 39, and 54 weeks post-treatment.

Before treatment with the bandages, PCP was detected in soil samples collected 10 cm from poles 1 and 2 which had been groundline treated 12 years previously. Poles 3 and 4 had not been retreated, and PCP was not detected (at the level of 1 mg/kg dry soil) near these poles, prior to the current retreatment program. For all the poles tested, significant amounts of PCP were found only within 10 cm of the poles, at depths of 10, 50 and 100 cm, over the entire 54 weeks of the study. The other samples, at 50 and 100 cm from the poles, were outside the zone of soil disturbed during the bandage application. They did not show any PCP contamination, except for a number of highly suspect values for pole 2 and 39 weeks post-treatment, which should probably be disregarded, according to the authors of the report.

The method of pole re-treatment used in this study differs from that used by Ontario Hydro, as mentioned above, and these differences would likely have a significant effect on the expected extent of migration of PCP from the poles. The addition of sodium borate will increase the pH of the grease used for re-treating, increasing the ionization of PCP and leading to greater solubility and leaching. The soil pH ranged from about 5 to 6, so the phenol form would predominate within a short distance, and adsorption to soil would occur. The polyethylene-coated bandage would tend to limit the amount of lateral movement of PCP away from the poles, at least in the top metre of soil.

4.4 Ontario Hydro Preliminary Study

4.4.1 Study Methods

Three poles in the Newmarket, Ontario area were chosen for this preliminary study, which has been described fully in Mortimer (1988a). Pole 1 was originally full-length treated with the standard 5% Penta-in-oil treatment prior to installation in 1955 and was groundline retreated in 1982. Pole 5, installed in 1982, had been full-length treated and had not yet been groundline re-treated. It appeared to be quite dry. The third pole, installed new in 1985 (Pole 6) was chosen because it had a very black greasy appearance with a pool of black material at the base of the pole (known as "bleeder" pole).

Two methods of soil sampling were used. Soil cores were taken by pounding a 1.5-m long, 5-cm diameter aluminum tube into the ground, withdrawing the tube and capping both ends. The soil-containing tubes were then frozen. Later the tubes were cut into 25 cm lengths and the contained soil from each segment was put into a clean, labelled Mason jar and mixed. Due to increasingly wintry conditions during the sampling period, subsequent soil samples were taken from the top 25 cm along one transect only, using a stainless steel, Oakfield soil auger tube. The samples were placed directly into Mason jars and the tube was rinsed clean and wiped dry between samples.

For the first pole (Pole 1), soil cores were taken along two perpendicular transects. Soil cores were taken at distances of 0.25, 0.50, 1.0, 2.0 and 5.0 m from the pole in both directions. For the other poles (Poles 5 and 6) only surface soil samples were taken, due to the difficulty of obtaining cores from freezing ground. Soil samples from around Poles 5 and 6 were also taken at 0.25, 0.50, 1.0, 2.0 and 5.0 m from the pole.

4.4.2 Results and Discussion

The chemical analysis of the soil samples was done by Zenon Environmental, Inc. of Burlington, ON. The soil pH for Poles 1, 5 and 6 was between 8.2 and 8.5. The soil moisture content was 17 to 23 per cent. Table 3 shows the results of the analyses for pentachlorophenol.

TABLE 3

PENTACHLOROPHENOL LEVELS IN SOILS NEAR PCP-TREATED POLES IN SOUTHERN ONTARIO

Pole 1. 1955 Penta-treated pole, groundline re-treated 1982

At the pole, surface soil concentration = 550 ppm

	Depth (m)	Concentration (ppm)
At 0.25 m from the pole (10 inches)	0.30	0.11
	0.61	tr (<0.05)
	0.91	ND
	>0.91	ND

At greater distances (0.5, 1.0, 2.0, 5.0 m) not detected.

Pole 5. 1982 Penta-treated pole - surface soil only

No detectable PCP in top foot of soil, at distances of 0.25, 0.5, 1.0, 2.0 and 5.0 m from pole.

Pole 6. 1985 Penta-treated pole (bleeder) - surface soil only

Distance from Pole (m)	Concentration (ppm)
0.25	2.3
0.50	ND
1.0	ND
2.0	ND
5.0	ND

Stanlake and Finn (1982) sampled soil from 0.4 and 0.15 m away from a PCP-treated utility pole in New York, and found levels of 76 mg/kg (76 ppm). In the present study, pentachlorophenol was not detectable in the soil around treated wood poles at distances greater than 0.25 m from the pole, with a lower detection limit of 0.05 ppm.

PCP concentrations decrease sharply within this distance (from 500 ppm to a few ppm). There are several possible explanations for this observation:

1. Very little PCP leaches from the installed poles.

2. The PCP that leaves the poles does so in the first year or two following installation and is not detectable after that.

3. The soil PCP concentration is rapidly decreased by biodegradation.

4. The soil PCP is transported away from the poles either in an immiscible oil phase or dissolved in water.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Migration and Persistence

The use of PCP as a wood preservative in Ontario has undoubtably contributed to the ambient levels of PCP in most environmental compartments, wildlife and humans. The major sources appear to be wood treatment facilities with poor environmental protection practices, allowing treatment wastes and post-treatment drip residues to discharge to nearby water bodies, or to soil surfaces. The ultimate environmental fate is pH dependent, as demonstrated by the fugacity models. Along the path followed by a PCP release, however, a uniform pH regime would not necessarily be expected to apply, with, for example, soil pH levels considerably higher than nearby surface water pH levels. This could give rise to the situation in which dissociated pentachlorophenate migrates quickly through a high pH soil, then reassociates to the more toxic pentachlorophenol as it reaches an acidic water body. Also, pH conditions vary across the Province according to geologic parent material, vegetation type, precipitation acidity and quantity, local industry, etc. These factors must be borne in mind when attempting to make a general statement about PCP fate and effects.

Accidental spills and releases aside, as long as PCP remains in the treated wood or in the adjacent soil, protecting the treated wood from fungal attack, the concern for environmental contamination is minimal. The extent to which PCP will be taken up by plants growing in PCP-contaminated soil is not known. Other than this concern, soil contamination is not a problem in most cases as bound PCP will biodegrade with time. It is when the PCP leaves that site of application and moves toward ground or surface water that environmental contamination becomes a possibility.

5.2 Research Needs

Figure 1 shows the pathways to be quantified in order to assess the potential for environmental degradation as a result of PCP contamination of the area adjacent to a treated pole. The following studies are required to quantify the extent of PCP migration and persistence. Some have been initiated by the people named, others are still at the proposal stage.

1. Biodegradation rates of PCP under Canadian environmental conditions have not been adequately determined. A. Seech at the Wastewater Technology Centre in Burlington, Ontario, has begun investigating the performance of various microbes for use in remediating contaminated sites.

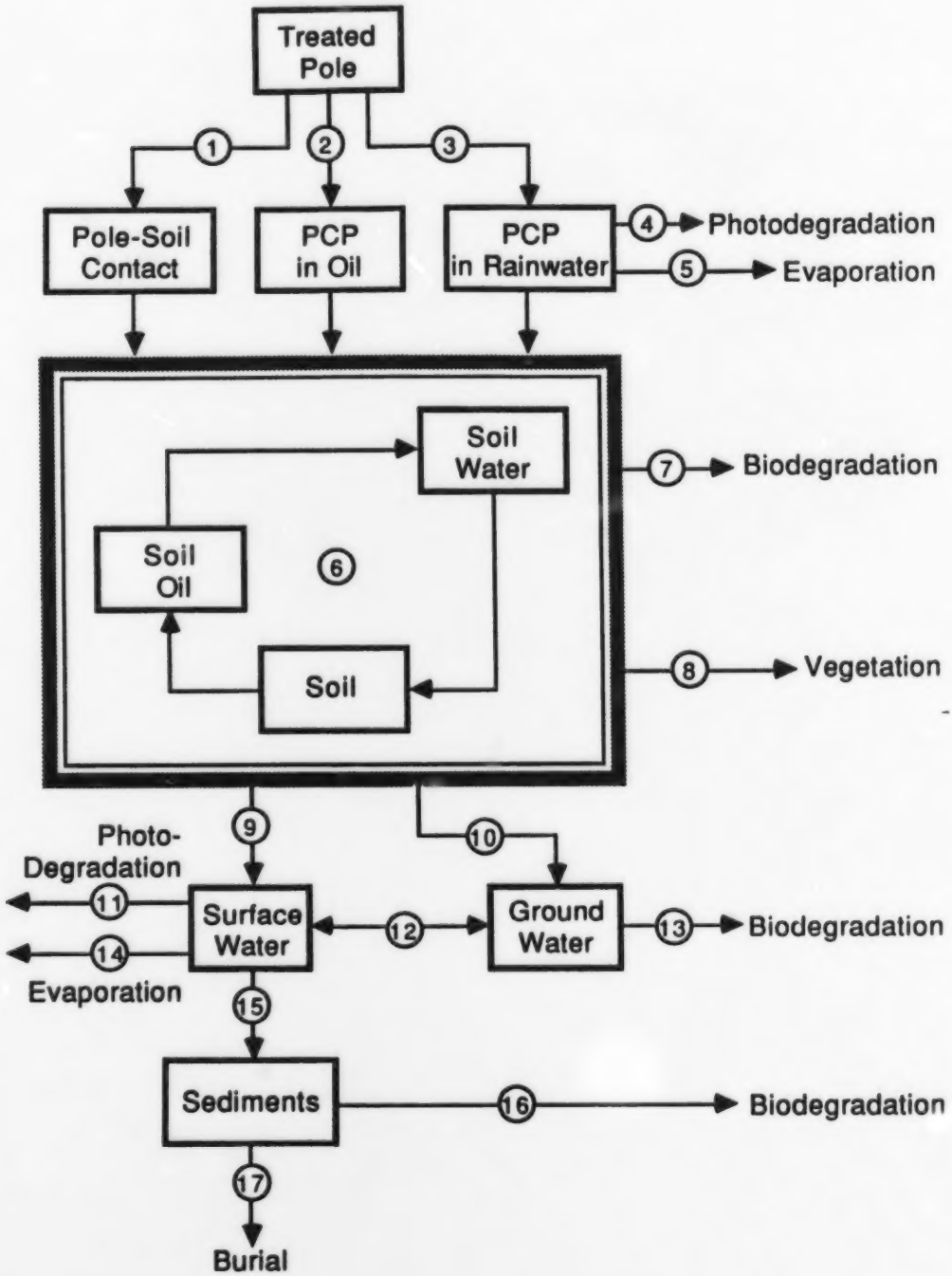

FIGURE 1

ENVIRONMENTAL PATHWAYS OF PCP

2. Leaching rates of PCP from treated wood under various pH-rainfall regimes and the toxicity of the leachate is the subject of a Masters student project at the University of Guelph, under the supervision of K. Solomon at the Canadian Centre for Toxicology. Funding is being provided by Distribution Operations Department, Ontario Hydro.

3. A laboratory study of the adsorption of PCP to Canadian soil, including partitioning between water/soil/oil phases under different pH conditions has been started by W. Mortimer. Funding is being provided by Ontario Hydro Research Division and the National Science and Engineering Research Council (NSERC).

4. A survey of the current extent of PCP contamination near poles of various ages and preservative treatments in different soil conditions is the subject of a proposal to the Canadian Electrical Association (CEA) by W. Mortimer and S.H. Hawthorne of Ontario Hydro Research Division.

5. A survey of the soil and water bodies near pole storage yards should be conducted. Poles may be held for a year or more during their most "leaky" stage, in regional or local storage yards prior to installation. During this time, contamination of the yard and nearby water bodies may occur. A need exists for a field sampling program to ensure that the storage areas do not become contaminated. If contamination has occurred in the past, the need for remedial measures should be evaluated. A small sampling program has been undertaken by B.M. Allen, Transmission Environment Department, Ontario Hydro, but no results are available at this time.

6. Out-of-service poles in Ontario are usually given away or sold to the public. Depending on what, if any, changes in legislation occur regarding PCP availability to the public and the disposal of PCP in landfills, alternative disposal/destruction of poles may be required. The first need is for the determination of the distribution of PCP within old poles. It may be, for example, that the amount of PCP remaining in the top portion of the pole is insignificant. Secondly, a means of removing the residual PCP from wood fibres, possibly by chemical or biological means, should be identified and, if needed, developed to full-scale operation. Research in this area has been initiated by D. Allen at the University of Toronto in collaboration with W. Mortimer. Funding is being provided by Ontario Hydro Research Division.

Taken together, these studies will allow a more complete understanding of the environmental fate of PCP as used by utilities for wood pole preservation, and will provide the information necessary to minimize the negative environmental effects.

Approved by:

D.J. Dodd
Manager
Chemical Research Department

WPM/mf

Prepared by:

W.P. Mortimer
Engineer
Environmental Science Section

Reviewed by:

O.T. Melo
Supervising Engineer
Environmental Science Section

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